EA417
Flight Test III

Static Margin

I. *Purpose*

To determine the stick-fixed and stick-free neutral points.

II. *References*

1. Etkin, "Dynamics of Flight — Stability and Control", Sections 2.1–2.9.

III. *Discussion and Theory*

Aircraft stability is analyzed by considering small disturbances from equilibrium flight and the reaction of the aircraft to these disturbances. A perturbation in pitch, roll or yaw produces changes in pressure distribution over the aircraft, giving rise to forces which cause changes in the moments about the center of gravity.

An unbalanced pitching moment, for instance, tends either to restore the aircraft to its original equilibrium state or to increase the amplitude of a pitch disturbance; the former describes a longitudinally, statically stable aircraft, the latter a longitudinally statically unstable aircraft (see Figure 3–1).

For equilibrium flight the pitching moment about the center of gravity, C_m, is zero, i.e., the aircraft is said to be balanced or trimmed. In a conventional configuration, the horizontal tail provides the balance moment. In order to permit equilibrium flight at various speeds (angles of attack), the balance or trim point must be changed. An elevator can be used to accomplish this change, as shown in Figure 3–2.

If we look again at the family of C_m vs α curves with various elevator deflections and then plot the elevator angles to trim (i.e., δ_e necessary to make $C_m = 0$ for a given α), a plot such as shown in Figure 3–3 results.

The negative slope of $d\delta_e/d\alpha$ in Figure 3–3 indicates a normal c.g. position, i.e., it is necessary to push the stick forward to fly faster (i.e., to decrease α). Progressively aft c.g. locations require less elevator deflection to change the angle of attack, as shown in Figure 3–4.

Because most actual aircraft do not have angle of attack indicators it is common to assume that $\partial/\partial\alpha \equiv \partial/\partial C_L$ on the basis that C_L is a linear function of α below

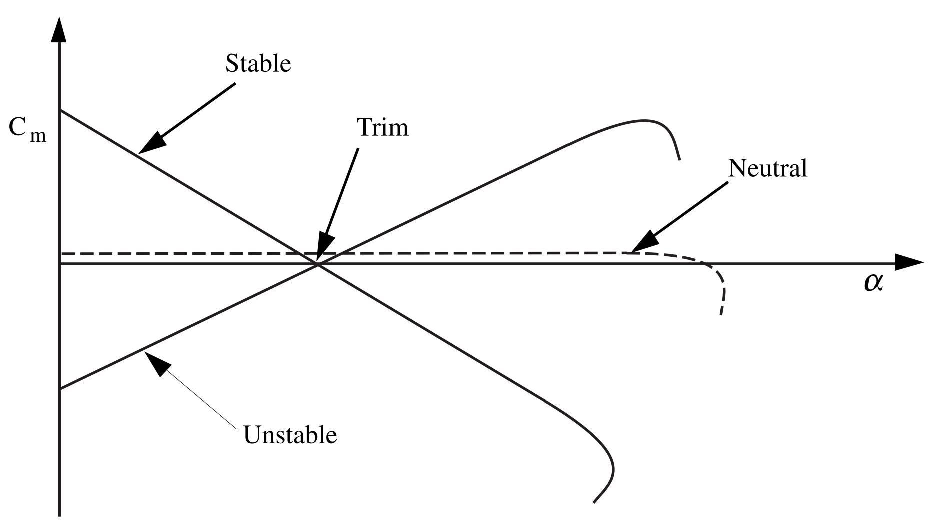

Figure 3–1. Pitching moment vs angle of attack.

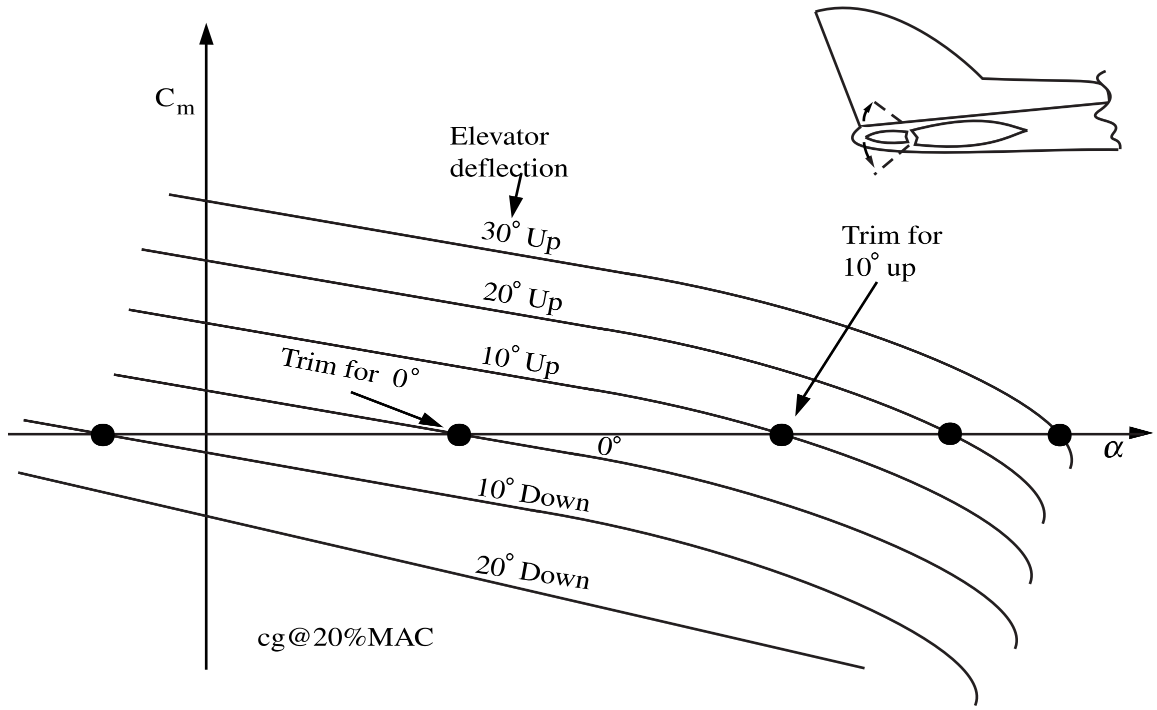

Figure 3–2. Effect of elevator deflection on the trim point.

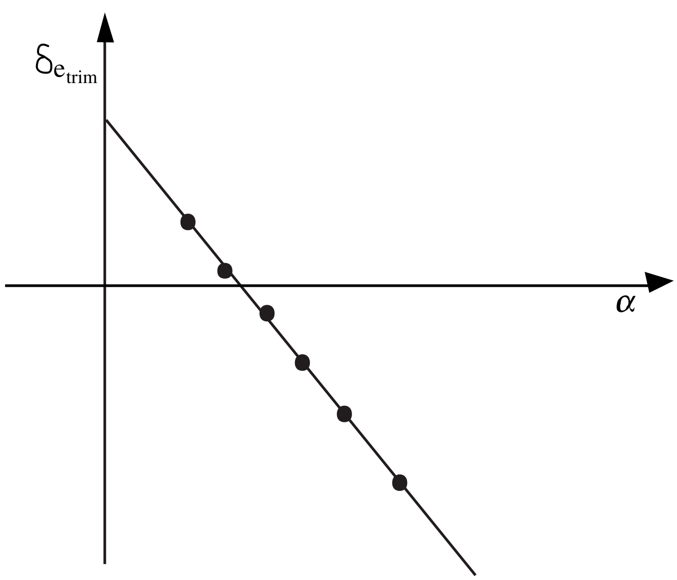

Figure 3–3. Elevator angle to trim.

stall. This implies that $C_{L_{\text{trim}}}$ is a function neither of Mach number nor of dynamic pressure (see Etkin), i.e., C_L is a function of α only, and hence $\partial\delta_e/\partial C_L = \partial\delta_e/\partial\alpha$. Furthermore, recall that

$$\text{Lift} = {}^1\!/\!_2\rho V^2 C_L S = {}^1\!/\!_2\rho V^2 a\alpha S$$

which for constant angle of attack and lift curve slope implies that $C_L \sim V^2$.

Stick-fixed Stability

Determining and plotting $\delta_{e_{\text{trim}}}$ vs $C_{L_{\text{trim}}}$ (really V^2_{trim}) for various nondimensional c.g. positions, and then plotting $\partial\delta_e/\partial C_{L_{\text{trim}}}$ as a function of the nondimensional c.g. position, $h = x_{c.g.}/\bar{c}$ (where $\bar{c}$ is the mean aerodynamic chord), as shown in Figure 3–5 suggests that a c.g. location exists where $\partial\delta_e/\partial C_L$ is zero; i.e., where only one particular elevator angle is required for any speed. This c.g. location is called the *stick-fixed neutral point*, h_n. Note the use of the partial derivative here.

Recall that the static margin is defined as the difference between the actual c.g. position and the stick-fixed neutral point expressed as a decimal fraction of the mean aerodynamic chord and is one measure of the stability of the aircraft.

Stick-free Stability

The horizontal tail provides longitudinal static stability. Let us consider the effect of freeing the elevator on longitudinal stability. Assume that the control system is frictionless and the elevator weightless. If the elevator is freed under these circumstances,

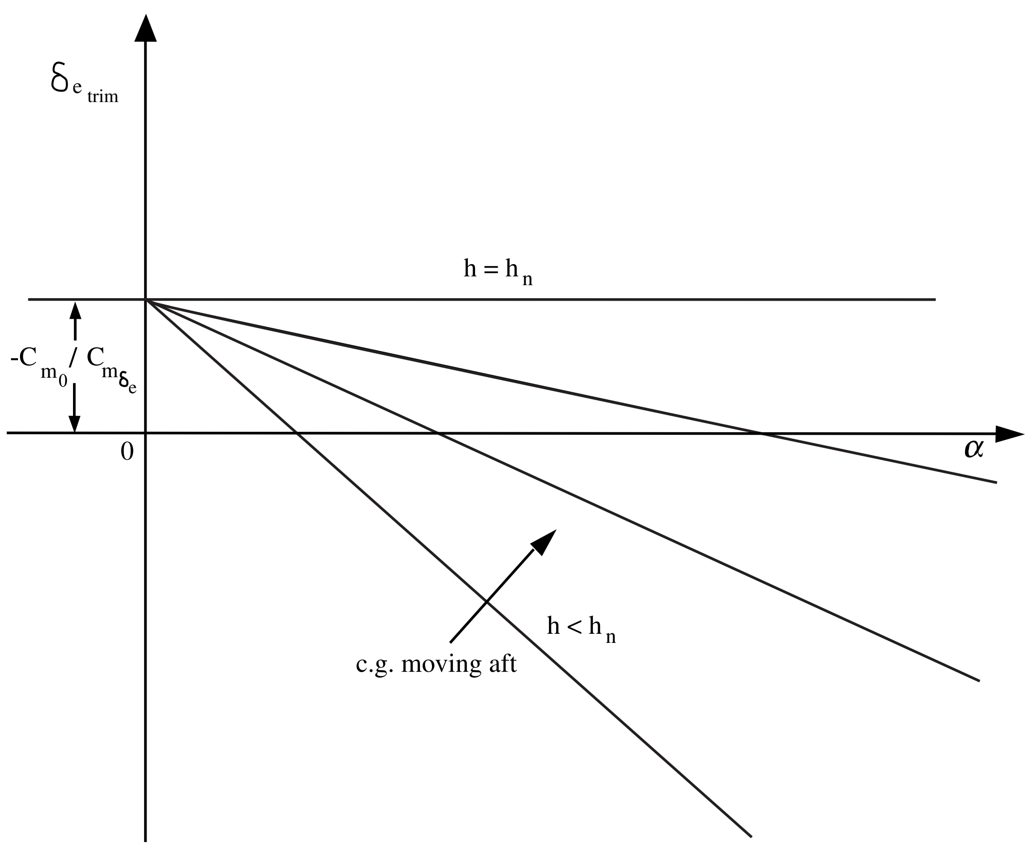

Figure 3–4. Elevator angle to trim at various c.g. positions.

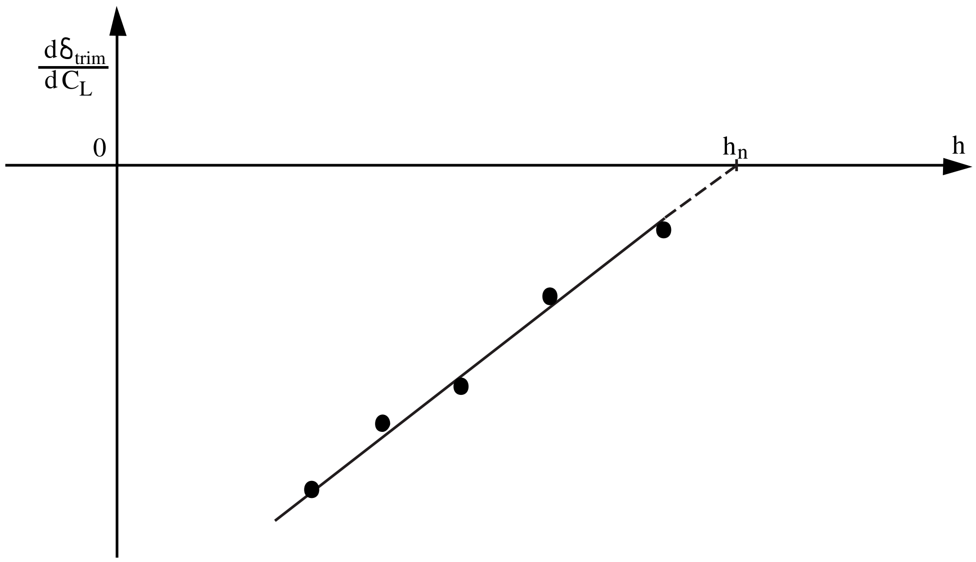

Figure 3–5. Determination of stick-fixed neutral point from flight test.

it tends to stream with the wind. The elevator floats up or down, depending on the angle of attack of the tail. The effect is as though the horizontal tail is reduced in size by cutting off the elevator. This reduces the static stability of the aircraft. As a result, the stick-free neutral point is usually forward of the stick-fixed neutral point.

Recall that as the c.g. of an aircraft moves aft less elevator deflection is required to change the equilibrium lift coefficient. Consequently, the pilot is required to exert less force to move the elevator. A plot of elevator hinge moment coefficient as a function of lift coefficient for various c.g. locations, is shown in Figure 3–6.

Plotting the slopes of these lines as a function of nondimensional c.g. location shows that there must be a c.g. location where $dC_{H_e}/dC_L = 0$; i.e., there is no change in stick force necessary to fly at various speeds. This c.g. location is called the *stick-free neutral point* (see Figure 3–7).

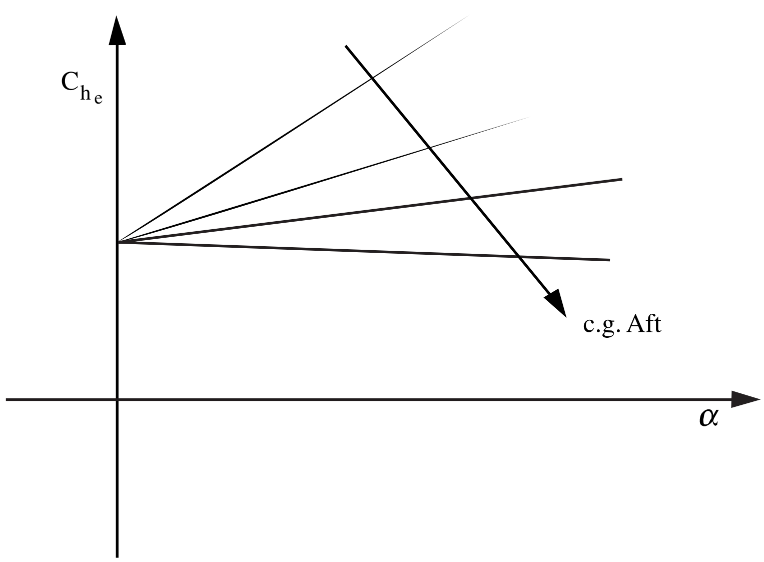

Figure 3–6. The effect of aft movement of the c.g. on elevator hinge moment.

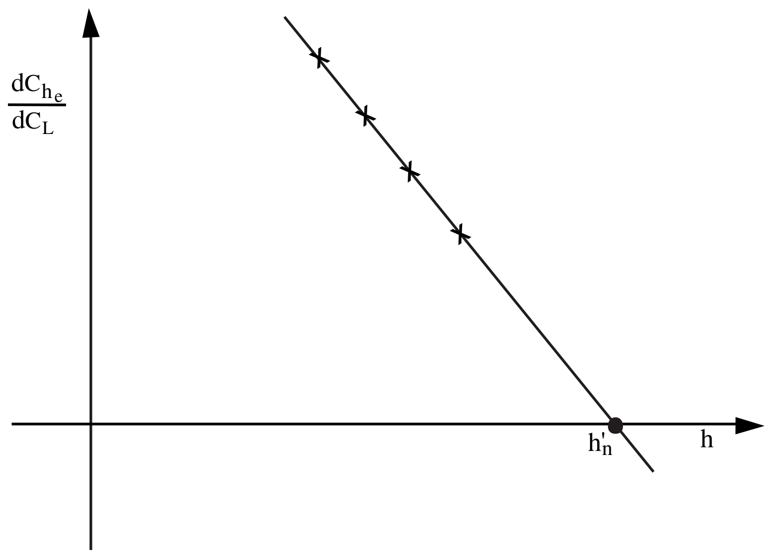

Figure 3–7. Determining the stick free neutral point from flight test.

V. *Procedure*

At a convenient reference altitude, set the elevator trim tab to zero. Establish steady flight at approximate 10 kt increments in the following order: 80, 90, 100, 110, 120, 130, 140, 150, 160 kts. Read the elevator angle to trim at each airspeed.

Students Shall

1. Prior to flight, record aircraft tachometer reading and fuel quantity.
2. Determine aircraft weight.
3. Insure that 29.92 in Hg is set in the Kohlsman window of the altimeter.
4. Record the following data at each airspeed:

    Elevator angle (δ_e;)
    Trim tab angle (δ_t;)
    IAS (kts);
    Altitude;
    OAT;
    Tachometer reading;
    Fuel remaining.

VI. *Flight test report requirements*

7. Determine and plot:

    δ_e as a function of C_L for each c.g. location;
    $d\delta_e/dC_L$ as a function of h;
    C_{H_e} as a function of C_L for each c.g. location;
    dC_{H_e}/dC_L as a function of h.

   Relate the data to the standard aircraft weight.

8. Using the results obtained in this flight test with different loadings (c.g. locations), determine the power on stick-fixed neutral point expressed as a decimal fraction of the mean aerodynamic chord. Determine the static margin.

Include a set of detailed sample calculations. Use any run you desire.